(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 169 431 A1

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: 85108445.9

(22) Date of filing: 08.07.85

(51) Int. Cl.4: F 23 R 3/34
F 23 R 3/04

(30) Priority: 10.07.84 JP 143851/84
10.07.84 JP 143852/84

(43) Date of publication of application:
29.01.86 Bulletin 86/5

(84) Designated Contracting States:
FR GB

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(54) **Gas turbine combustor.**

(57) The present invention relates to a gas turbine combustor (3) which produces a little amount of NOx. The combustor (3) has a head combustion chamber (11) and a rear combustion chamber (12) which is larger in diameter than the head combustion chamber (11). The head combustion chamber (11) is provided with an axially extending hollow frustoconical tubular member (13) to form an annular combustion space therein, air holes for axially jetting air into the annular combustion chamber, air holes formed on the peripheral wall for injecting air and a plurality of fuel nozzles (22) projected into the annular combustion space for injecting fuel into vortex formed by the air jet and the injected air flow whereby the flame is stabilized and lean combustion can be performed. The rear combustion chamber (12) has a fuel and air supply means on the upstream side which consists of air inlets formed by whirling vanes and fuel nozzles disposed in the air inlets so that fuel and air are mixed well. The fuel and air mixture is jetted substantially axially while whirling it so that hot spot formation is avoided, NOx formation is limited extremely.

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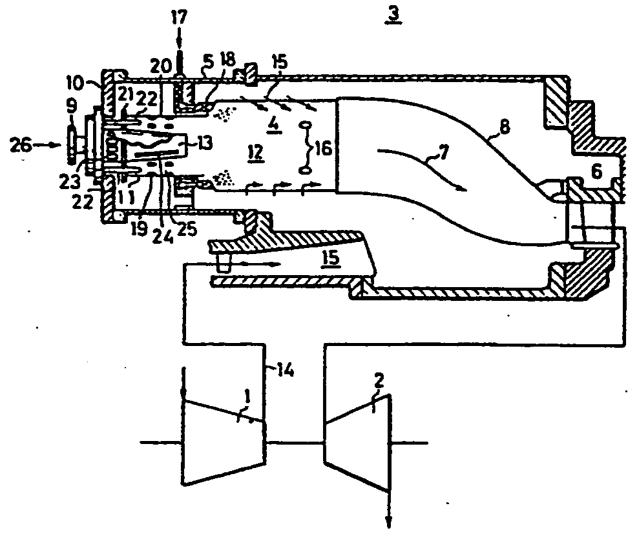
FIG. 1



TITLE OF THE INVENTION

GAS TURBINE COMBUSTOR

BACKGROUND OF THE INVENTION

The present invention relates to a gas turbine combustor which produces NOx in relatively small amounts, and more particularly to a gas turbine combustor, of a two-stage conbustion system, which burns a gaseous fuel such as natural gas (LNG) producing very lettle NOx.

A method of reducing NOx in the gas turbine combustor is roughly divided into a wet-type method which uses water or wter vapor, and a dry-type method which is based upon the improved combustion performance. The former method which employs a medium such as water, water vapor so that turbine efficiency decreases turbine efficiency. The latter method of restraining combustion is superior to other method, however, since this method is to sustain combustion with a full lean mixture at a low uniform temperature, carbon monoxide is generated in large amounts though NOx is generated only in small amounts.

During combustion, in general, formation of NOx is dominated by a combustion gas of a local high-temperature portion (higher than 1800°C) in the combustion region. NOx is formed mainly by the oxidation of nitrogen contained in the unburned exhaust and by the oxidiation of nitrogen contained in the combustion air. These two values will hereafter be called the thermal NO and the fuel NO. The thermal NO is largely dependent upon the oxygen concentration and the reaction time, which in turn are affected considerably by the gas temperature. Therefore, combustion can be sustained while effectively reducing the formation of NOx if a uniform temperature lower than 1500°C is maintained without permitting the high-temperature regions to occur in the combustion.

To reduce the formation of NOx in the gas turbine, the lean diffusion combustion method has heretofore been

most advantageously employed, since a gas turbine combustor permits a relatively large air flow rate with respect to the fuel flow rate, and it makes it possible to control the distribution of air in the combustion chamber to some extent. The chief concern is that combustion is performed over a low uniform temperature range, by reducing combustion temperature, facilitating mixing, and reducing time during which NOx is formed.

A conventional technique for realizing the above-mentioned combustion has been disclosed, for example in Japanese Patent Publicaiton No. 20122/1980, in which a plurality of fuel nozzles are annularly arranged in an annular combustion chamber, and the air and water vapor are introduced from the downstream side of an inner cylinder installed coaxially of the combustion chamber. The combustor employs a combustion method in which the fuel is suppled into the combustion chamber and dispersed over the cross section thereof, so as to make uniform combustion temperature and to decrease gas temperature downstream of the combustion chamber. Further, flame stablilizers consisting of swirlers are installed around the fuel nozzles. The stabillizer stabilize flame in the region of whirling stream formed by whirling air, which per se is known by Japanese Patent Laid-Open No. 202431/1982. During combustion, however, extremely hot gases are present in the region of the whirling stream in order to maintain and stabilize the flame near the fuel nozzles, thereby making it difficult to reduce NOx. In the flame stabilizer having air whirlilng vanes, a relatively high air flow velocity ($V > 30$ m/s) is necessary to function within its effective range where the Reynolds number Re is greater than 10^5. Further, as the flame is reduced in length, combustion is likely to take place most rapidly near the fuel nozzles. Moreover, an intense flame stabilization at a localized high-temperature portion in the region of whirling flow which is 1 to 2 times wider than the diameter of the flame

stabilizer, induces the formation of NOx. Therefore, even if a plurality of fuel nozzles having a conventional flame stabilizer are provided, they are unlikely to greatly reduce the formation of NOx. Particularly for combustion in which NOx is formed in small amounts, it is essential to provide a flame stabilizing mechanism that effectively reduces the rate of NOx formation. The mode of combustion is greatly affected by the flame-stabilizing characteristics.

A combustor employing the two-stage combustion system has been disclosed, for example, in Japanese Patent Laid-Open No. 41524/1982. In this known technique, a pre-mixture gas of fuel and air is introduced into a first-stage (head) combustion chamber where combustion is effected by a single nozzle. Then, fuel and air are simultaneously supplied via air holes into a second-stage (rear) combustion chamber on the downstream side, in order to sustain low-temperature combustion with a lean mixture so that NOx is formed in reduced amounts.

However, according to the method in which a combustion flame is formed in a distributed manner by a single nozzle in the head combustion chamber, and the fuel in the second stage is introduced downstream, it is difficult to limit the formation of NOx. That is, formation of NOx can be suppressed in the combustion of the second stage by introducing fuel at the second stage. In the combustion taking place in a distributed manner in the first stage, however, hot spots are formed over wide areas, making it difficult to suppress the formation of NOx. Furthermore, the single nozzle which exists on the axis of the combustion chamber makes it difficult to properly mix the fuel with the air stream that flows from the side walls of the combustion chamber, giving rise to the formation of hot spots. Thus, with the conventional combustor having a single fuel injection nozzle at the head of the combustion chamber, it is difficult to

greatly limit the formation of NOx. Even with the two-stage combustor as described avove, it is essential to limit the formation of NOx in the first stage and in the second stage, in order to strictly limit the total formation of NOx. In the conventional technique having a single fuel nozzle on the axis of the head portion, however, it is not possible to strictly limit the formation of NOx.

Further, even if the above-mentioned multi-fuel nozzles with the conventional flame stabilizers are employed for first stage combustion in place of the above-mentioned single fuel nozzle, the formation of NOx is not greatly reduced in amounts. The flame generated by the multi-fuel nozzles is stabillized too firm to prevent the formation of local high temperature portions. NOx formation takes place near the nozzles, and the produced NOx is reduced in the second stage combustion.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a gas turbine combustor which effectively stabilizes the flame in a combustion chamber at the head portion of the combustor, and which facilitate a kind of combustion which produces NOx in relatively small amounts.

Another object of the present invention is to provide a gas turbine combustor of a two-stage combustion system which employs a fuel diffusion method that does not form local high-temperature combustion portions in the head portion, thereby limiting the formation of NOx, and in which the mixing space is small so as to facilitate mixing fuel with the air, and which establishes low-temperature lean combustion in the head portion and in the rear portion in order to limit the formation of NOx, i.e., in order to greatly limit the formation of NOx.

The present invention supplies the fuel in a distributed manner in order to eliminate the presence of

high-temperature spots, the so-called hot spots in the combustion portion that governs the formation of NOx. That is, a gas turbine combustor according to the present invention is provided with a plurality of fuel nozzles arragned in annularly dispersed manner for each of first and second combustion stages in order to disperse fuel and promote the mixing of fuel with air, a hollow frustoconical tubular member in the head combustion chamber thereby providing an annular combustion space therein which defines a small mixing space to eliminate hot spots that may take place in the centrol portion in the head combustion chamber, and to properly mix the fuel and the combustion chamber, and to properly mix the fuel and the air in the head cobustion chamber. The fuel nozzles for the first combustion stage are arranged so as to inject fuel into eddy or vortex flow formed by air jet from the end wall of the head combustion chamber and air flow from the peripheral wall of the head combustion chamber, whereby the flame resulting from combustion of the fuel is stably maintained under relatively lean conditions and lean-fuel low-temperature combustion is effected. In the rear combustion chamber for the second combustion stage, furthermore, the tip air holes of the fuel nozzles are located in the air stream to promote the mixing of the air with the fuel and the fuel and air mixture is injected in parallel to the axis of the chamber, thereby to eliminate the occurence of hot spots and to greatly reduce the formation of NOx.

BRIEF DESCRIPTION OF THE INVENTION

Fig. 1 is a sectional view of a gas turbine combustor according to an embodimant of the present invention ;

Fig. 2 is a partial enlarged sectional view of Fig. 1 ;

Fig. 3 is a sectional view taken along a line III-III in Fig. 2 ;

Fig. 4 is a perspective view of a head combution chamber according to another embodiment of the present invention ;

Fig. 5 is a partially sectional perspective view of the second stage fuel supply portion of the gas turbine combustor shown in Fig. 1 ;

Fig. 6 and 7 each are a schematic view illustrating flow pattern of the air and fuel in the head portion of the combustion chamber ;

Fig. 8 is a graph showing flame stability depending upon the protruding length of the fuel nozzle ;

Fig. 9 is graph showing a relationships between NOx and CO concentrations and the fuel nozzle protruding length ;

Fig. 10 is a graph showing a relationship between the flow speed for blow out and LA/LC.

Fig. 11 is a graph showing a relationship between the NOx concentration and LB/LF;

Fig. 12 is a graph showing an excess air ratio in various positions in the head combustor ;

Fig. 13 is a schematic partial view of a head combustion chamber according to another embodiment of the present invention

Fig. 14a and 14b each are a modification of the head combustion chamber shown in Fig. 13 ;

Fig. 15 is a graph showing relations of NOx concentration to turbine load ;

Fig. 16 is a schematic view for explaining the formation of flame ;

Fig. 17 is a diagram illustrating in detail the fuel supply portion ;

Fig. 18 is a diagram illustrating in detail the fuel supply portion according to another embodiment ;

Fig. 19 is a section view showing the fuel supply portion of the second stage according to another embodiment ;

Fig. 20 and 21 are diagrams showing the direction of

supplying fuel in the second stage and interfering condition of the flames ;

Fig. 22 is a diagram of characteristics showing a relation between the length of the head combustion chamber and the effect for reducing NOx ;

Fig. 23 is a diagram of characteristics showing a relation between the gas turbine load and the NOx conentration ; and

Fig. 24 is a diagram of characteristics showing temperature distribution of flames.

Description of the Preferred Embodiments.

An embodiment of a gas turbine combustor according to the present invention is described hereinafter referring to the drawings.

In Figs. 1, the gas turbine is constructed of a compressor 1, a turbine 2, and a combustor 3 which is made of an inner casing such as a cylinder 4, an outer casing such as a cylinder 5 and a tail cylinder 8 that introduces a combustion gas 7 the stator blades 6 of the turbine. An end cover 10 is mounted on a side end of the outer cylinder 5 to install a fuel nozzle body 9 of first stage. The combustor is further equipped with an ignition plug 100 as shown in Fig. 2, a flame detector that senses the flame not shown, and other components not shown. The inner cylinder 4 is divided into a head combustion chamber 11 and a rear combustion chamber 12 having a diameter larger than that of the head combustion chamber 11. A hollow frustoconicel tube 13 hereafter referred to as a cone 13 is inserted concentrically in the head combustion chamber 11, the cone 13 being narrowed from the upstream side toward the downstream side thereby forming an annular space 25 which gradually increases in sectional area from the upstream side to the downstream side, and having front end with fine air pores.

An air stream 14 compressed by the compressor 1

passes through a diffuser 15, is routed around the tail cylinder 8, and is introduced into the combustion chambers via louvers 151 and lean air holes 16 formed in the inner cylinder 5, via air holes 18 for burning fuel 17 of a second stage, via air holes 19 for combustion formed in the head combustion chamber, and via louvers 20. Fuel nozzles 22 of the first stage annularly provided on the nozzle body 9 penetrate through the end wall (liner cap) 21 of the head combustion chamber, and have a plurality of fuel injection holes 221 to inject fuel into the head combustion chamber.

The cone 13 has inlet holes 23 for introducing the air, as well as a plurality of cooling-air holes 24 that are annularly arranged in each of a plurality of rows so that the air will flow along the surface of the cone 13.

Figs. 2 and 3 illustrate in detail the construction of the combustor.

The plurality of fuel nozzles 22 are arranged annularly as shown in Fig. 3 and penetrate through the end wall 21 , with annular spaces for an passages fromed between the end wall holes 28 and the nozzle surfaces. The fuel injection holes 221 of the nozzles 22 are located upstream of head combustion chamber and opened nearly at right-angles to the axis of the inner cylinder 11. The fuel 27 jetted therefrom is mixed with the air introduced through the air holes 19a, 19b, 19c and 19d formed in the wall of the head combustion chamber, so that combustion is sustained. Unlike a single injecton nozzle employed by a conventional art, the fuel nozzles 22 are located close to the side wall of the head combustion chamber 11. Therefore, the fuel is quickly mixed with the air introduce through the air holes 19a, 19b, 19c, 19d, and with the air stream from the air holes 28, making it possible to increase the cooling effect of the air at the initial stage of combustion. Therefore, development of hot spots can be suppressed and the formation of NOx can be reduced. Thus, the fuel

injection holes 221 are provided in a plurality of number at positions close to the side wall of the head combustion chamber 11, in order to promote the above-mentioned mixing effects, as well as to disperse the flame or to establish a so-called divisional combustion. Owing to these synergistic effects, formation of NOx can be reduced greatly.

To further limit the formation of NOx, provision is made for the cone 13. Therefore, the cooling effect and the mixing effect are not lost. The air through the air holes 19a, 19b, 19c, 19d formed in the side wall of the head combustion chamber is not allowed to reach the central portion. Furtheremore, the formation of NOx can be greatly limited since the flame is effectively cooled by the cone and is cooled from the inner side by the cooling air 20b that is ejected from a plurality of fine holes 24 formed annularly in the surface of the cone 13.

The fuel nozzles 22 facilitate mixing the fuel with the air introduced rupstream from the fuel injection holes depending upon the length by which they protrude into the combustor, and are a crucial factor in limiting the formation of NOx. Good mixing is obtained if the fuel injection holes are near the air holes 19a, and formation of NOx is strictly limitted.

The fuel injection holes 221 of the fuel nozzles 22 are positoned near the air holes 19a annularly arranged and forming a first air hole row.

As shown in Fig. 3, furthermore, long fuel nozzle 22a and short fuel nozzle 22b are arranged alternatingly to change the positions for injecting the fuel into the combustion chamber, for instance. In such a case, when the position of the group of air holes 19a is regarded as a reference position, the fuel nozzle 22a inject the fuel downstream from the group of air holes 19a, and the fuel nozzle 22b inject the fuel upstream therefrom.

Air and fuel supply means for the second stage as shown by Fig. 5 is provided on the inner cylilnder 4 on

the upstream side end of the rear combustor chamber 12 for second combustion stage. The air and fuel supply means consists of air inlets formed by a plurality of whirling vanes 36, and fuel nozzles 34 each disposed between the vanes 36. The fuel nozzles are mounted on a nozzle flange in which passages for fuel in are formed for supplying fuel into each fuel nozzles 34. The nozzle 34 has at the tip fuel injection holes.

The fuel and air supplying means for second sage will be deescribed further indetail later, referring to Fig. 17 to 19.

Fig. 6 and 7 illustrate flow patterns of the air and fuel near the head portion of the combustion chamber 11, wherein solid lines indicate the flow of air, and the chain lines indicate the flow condition of fuel.

The air flowing through gaps formed between the fuel nozzle 22 (22a or 22b) and the air holes 28 formed in the end wall 21 flows along the fuel nozzle 22, whereby a reverse flow takes place due to a pressure differential between the air jet and the air in space, and a relatively weak vortex flow is established around the fuel nozzles 22 on the upstream side thereof. The vortex flow includes upward flows and downward flows and is further reinforced by the reverse flow components produced by the air jet from the outer wall of the inner cylinder 4. Under the above-mentioned air-flow condition, when the fuel is injected via fuel nozzles 22b, 22a into the upstream portion ($La > Lf$) with respect to the air holes 19a of the first stage as shwon in Fig. 6, the fuel is taken in large amounts by the vortex region A and the fuel concentration increases. When the fuel is injected at a position behind the air jet ($La < Lf$) that flows via the air holes 19a formed in the outer wall of the inner cylinder as shown in Fig. 7, the fuel flows in very samll amounts into the vortex region A that is formed upstream form the fuel nozzles. It is

evident that the difference in the fuel concentration in the vortex flow region seriously affects the flame-stabilizing performance and combustion characteristics.

Fig. 8 and 9 illustrate experimental results related to flame stability and combustion characteristics determined by the length Lf of fuel nozzles 22 from the end wall 21 to the fuel injection hole 221. The stability of flame increases with the decrease in the length Lf of the fuel nozzles. Nox, however, is formed in increasing amounts. If the fuel nozzles 22a, 22b are lengthened, NOs is formed in reduced amounts, but unburned gases such as corbon monoxide and the like increase and the flame stability decreases.

With regard to the construction of the combustor, furthermore, length of the cone 13 constituting the combustion chamber and position of the air holes serve as other factors that greatly affect the combustion characteristics.

The air holes 28 are formed in a plurality of number in the end wall 21 at the head portion of the combustion chamber to surround the fuel nozzle 22. Or, the air may be introduced from positions inside or outside of the combustion chamber to sufficiently accomplish the object, provided it does not interrupt the vortex flow region but rather reinforces it. In the construction of this embodiment, in particular, the position of air holes of the first stage serves as a factor that controls the dimensions and intensity of the vortex flow region, and greatly affects the stability of flame.

Fig. 10 shows flame blow-out characteristics when the position of injecting fuel is maintained constant in relation to a ratio of a distance La between the side wall 21 and the first air hole row, to the width Lc of the annular combustion chamber at the end wall 21. The adaptable range of ratio La/Le is smaller than 0.6, the vortex flow region that contributes to stabilizing the flame decreases, and the combustion becomes less stable

due to the lean mixture that results from the surrounding flow of air and due to the decrease in the combustion temperature. When the ratio La/Lc is smaller than 0.5, it is difficult to ignite the mixture. When the ratio La/Lc is greater than 1.7, the vortex flow region increases noticeably. However, dead space is formed, and the temperature rises in this dead space, thereby making it difficult to reduce the formation of NOx. In the flame stabilizing mechanism of this embodiment, in particular, the flame is generated near the fuel injection holes of the fuel injection nozzles, and combustion is sustained by the combustion product (high-temperature gas) that flows back from downstream to upstream due to the surrounding air flow, and the flame is thereby stabilized.

Next, described below in detail are the cone 13 installed at the central portion of the inner cylinder 4 and the protruding length Lf of the fuel nozzles 22. When the cone 13 is used, a high-temperature combustion portion is less likely to form at the center of the combustion chamber than when the cone is not used. Since an annular combustion space or chamber is formed, this facilitates both dispersed fuel injection and mixing fuel with air introduced from the wall surface of the inner cylinder 4. Relatively lean combustion is thereby sustained so that a high-temperature portion does not develop. Therefore, less intense combustion can be accomplished which is less likely to form Nox.

Fig. 11 shows the relation between the concentration of NOx and the ratio of the length Lb of the cone to the protruding length Lf of the fuel nozzles 22 as the length Lb of the cone 13 increases, Nox is formed in reduced amounts. However, if the cone 13 is too long, the amount of air introduced decreasses at the head combustion chamber 11. The cooling function decreases on the wall of the head combustion chamber 11 and on the wall of the cone 13, and the temperature of the metal

rises thereby reducing reliability. If the length Lb of the cone 13 is reduced, fuel and air are not well mixed. The air is introduced in large amounts due to the pressure differential between the inside and the outside of the inner cylinder which pressure difference is caused by the enlargement of the annular combustion chamber into a cylindriacl combustion chamber during the combustion. Therefore, combustion is intense near the end of the cone 13, and NOx is formed in excessive amounts. Accordingly, the adaptable range for the cone 13 is Lb/Lf = 2.0 to 5.0.

Fig. 12 specifically shows the condition of air flow near the head portion of combustion chamber. The air is introduced in such amounts as to fall within combustible ranges at all times when the gas turbine is in operation, i.e., under light load or heavy load. With respect to the total amount of air in the head combustion chamber, air is introduced at a ratio of 8 to 20 % through the air holes 28 formed in the end wall 21 at the head portion, air is introduced at a rate of 10, to 23 % through the air holes 19a of the first row, and at a rate of 57 to 82 % with respect to the amount of air for combustion in the head combustion chamber through the holes (19a to 19d) of the second to forth row formed downstream.

The intensity of the vortex flow formed in the combustion chamber 11 at the head portion is governed by the relation between the amount of air introduced through the air holes 28 formed in the end wall 21 and the amount of air introduced through the air holes 19a. Therefore, when the values are smaller than the above-mentioned values, the stability of the flame decreases with the decrease in the intensity of vortex flow. Furtheremore, the stoicheometric mixing ratio (λ =1.0) shifts in the direction of excess fuel ratio under light load, and the ratio ralls outside the combustible range under heavy load, making it difficult to maintain good combustion. When the upper-limit values are exceeded, the

stoicheometric mixing ratio (λ = 1.0) is approached under heavy load without creating any serious problem. Under the light load, however, relatively lean combustion takes place, and the flame is unstabile. Therefore, combustion should be sustained by distributing the amount of air as described above.

Described below is means for supplying fuel that plays a very important role in constituting the combustor of the invention. First, if the above-mentioned embodiment is referred to, short fuel nozzles 22 (22b) for stabilizing the flame as protruding up in the vicinity of the air holes 19a for first stage combustion. The fuel nozzle 22 (22a) for combustion have a length 1.5 times the position of the air holes 19a. The fuel nozzles 22b for stabilizing the combustion and the fuel nozzles 22a for combustion are alternatingly arranged annularly maintaining a pitch which is nearly equal to the protruding length of the fuel nozzle 22b for stabilizing the fuel. The fuel nozzles 22 (22a, 22b) inject the fuel in a direction nearly perpendicularly to the longitudinal axis of the combustion chamber. In this combustion system, the flame of flame-stabilizing portion and the flame for combustion take place being separated axially and annularly in the combustion chamber. Therefore, since the flames are dispersed, combustion is sustained over a low uniform temperature range so as to form relatively little NOx. In order to effectively establish combustion, distance between fuel nozzles may be shortened both in axial and annular directions to provide more fuel nozzles. This, however, is limited by the size and shape of the combustor. Further, high-temperature regions are formed by the mutual interference of the flames. If the number of fuel nozzles is reduced, the fuel is not distributed well, and it becomes difficult to limit the formation of NOx. As described by way of an embodiment of the present invention, therefore, it is essential to provide three to four air hole rows,

for example, 19a to 19d in the axial direction to separately introduce the air into the head combustion chamber 11 arrangement of the full nozzles 22 annular direction keeps a distance such that the flames will not interfere with each other.

Fig. 13 illustrates another embodiment of the construction of a fuel nozzle. The nozzle 22c has fuel injection holes 22d and 22e for stabilizing the flame and for combustion.

Figs. 14a and 14b illustrate further another embodiment of a fuel nozzle. The fuel nozzles 22f, 22g and 22h, 22i are protruded from the side of the inner cylinder 11 and from the side of the cone 13, respectively.

The relation between the length of the head combustion chamber and the fuel supply position of the second stage produces a function as described below inclusive of the cone 13 located in the head combustion chamber 11. That is, in the annular space 25 in the head combustion chamber 11, it is essential that the first stage fuel is burned nearly completely. Even when the second stage fuel and air are supplied and burned, flow in the head combustion chambe 11 of the first stage should be held to a minimum. The head combustion chamber 11 should be so determined that the fuel of the first stage is mixed with the air introduced through the holes 19a to 19d and is burned almost completely in the annular space 25 defined by the inner wall of the head combustion chamber and the outer wall of the 13.

Fig. 16 shows the relation between the positions of the fuel and air supply means in the second stage and the NOx concentration. As the length of the head combustion chamber 11 is reduced, the fuel and the air are introduced from the second stage before the combustion is completed in the head combusiton chamber 11, whereby combusiton in the head portion is interrupted by the air from the second stage, and portions indicated by A are

quickly cooled. Therefore, unburned components such as carbon monoxide and hdyrocarbons are formed in large amounts, decreasing the efficiency of combusiton. Furthermore, if the second stage combustion is established under the above-mentioned condition, combustion takes place simultaneously in the first stage and in the second stage. Therefore, hot spots of high temperatures are formed in the combusiton initiating portion of the second stage, resulting in the formation of NOx in large amounts.

Further, increase in the length of the head combusiton chamber 11 causes the cooling area of the wall of the head combustion chamber to increase and, hence, permits the cooling air to flow in increased amounts. As the amount of cooling air increases as mentioned above, cooling air is introduced between the flame of the first stage and the fuel gas of the second stage when the fuel gas is to be introduced from the second stage. This adversely affects ignition from the first stage to the fuel gas of the second stage. For this reason, the length of the head combustion chamber 11 is not increased by more than a predetermined value. According to experiments conducted under the conditions of a combustion pressure of up to 10 atm and an air the temperature of up to 350°C, it was found that the length of the head combusiton chamber 11 should typically be from about 1.2 to about 2.0 as great as the outer diameter of the head combustion chamber 11, and should ideally be about 1.5 times that of the outer diameter of the head combustion chamber 11, though it may vary depending upon the diameter and length of the cone 13. Length of the cone 13 determine the volume of the head combustion chamber 11. Fundamentally, however, with the cone 13 being longer than the head combustion chamber 11, combustion gas expands in the rear combustion chamber 12 when combustion of the second stage is initiated, and the pressure loss (resistance) increases at the outlet

portion of the head combustion chamber 11 due to the acceleration of combustion gas. Therefore, less air is introduced in the head combustion chamber 11. Low-temperature combustion with a lean mixture is no longer sustained in the head combustion chamber 11 ; i.e., NOx is formed in large amounts, the gas temperature rises, and the rate of air flow decreases. Therefore, the temperature rises on the outer peripheral wall of the head combustion chamber 11, and the combustor becomes less reliable and its working life is shortened. Therefore, the inner cylindrical cone 13 should have such a length that limits the effect of gas acceleration loss caused by combustion in the second stage. For this purpose, the cone 13 should be shorter than the head combustion chamber 11, and should have a volume sufficient to withstand a sudden expansion of combustion gas even when the combustion gas is accelerated from the tip of the cone to the outlet of the head combustion chamber. According to experiments, the ideal length Lb of the cone 13 should satisfy the relation Lb/L=0.7 relative to the length L of the head combustion chamber 11. Space from the front end of the cone 13 to the rear end of the head combustion chamber should be so determined as to establish the above-mentioned dimensional relation. Here, if the ratio Lb/L is small or if the cone 13 is short, the flame of first stage combustion is formed on the portion of axis at the front end of the cone 13. Therefore, a high-temperature portion is formed in the portion of axis, and NOx is formed in large amounts. As the ratio Lb/L approaches 1, furthermore, NOx is generated in large amounts as described avove, and the temperature rises in the wall of the head portion. Accordingly, the cone 13 should be shorter than the head combustion chamber 11.

Through the same combustion tests as those mentioned earlier, it was found that to reduce the formation of NOx, carbone monoxide, and hydracarbons in the first and

second stages, the area of air openings relative to the head combustion chamber should be 50 to 55 % of the total opening areas, the area of air openings relative to the second stage should be 20 to 30 %, the air flow areas open to the rear combustion chamber should be 20 to 30 %, and the cooling areas open to the cone 13 should be 7 to 10 %. In particular, if the cone 13 is provided with air openings for combustion in addition to the openings for introducing cooling air, combustion is promoted by the air stream, and hot spots are formed. Therefore, the cone should be provided only with the holes for cooling air. If the area of air holes relative to the second stage becomes greater than 30 %, ignition is adversely affected. When this ratio is smaller than 20 %, it becomes difficult to effectively limit the formation of NOx. If the amount of air to the head combusiton chamber 11 is greater than 60 %, the mixture becomes so lean that carbon monoxide and hydrocarbons are formed in large amounts. If the amount of air is smaller than 40 %, on the other hand, the temperature of the metals rises and NOx is formed in large amounts.

Detailed construciton of the fuel and air supply means are illustrated in Figs. 17 to 19.

Fig. 17 shows enlargement of the fuel nozzles 34 and the whirling vanes 37. The whirling vane37 are in parallel to each other and inclined to the axis of the inner cylinder 4 to whirl the air. The nozzles 34 have at the tips injection holes 34 perforated in the radial and peripheral directions with respect to the inner casing 4. The tips portion is disposed in the air hole 33 at the central portion with respert to the cross-section of the air hole so that fuel injected through the hole 35 is mixed with air well.

Fig. 18 illustrates a modification of the whirling vane 37. The vane 37 has a bent portion (41a, 41b, 41c) which is parallel to the axis of the nozzle 34.

Fig. 19 shows another embodiment of the fuel and air

supply means according to the present invention. In this embodiment, the whirling vanes 37 are secured to both a supporting member 38 which is joined to the nozzle flange 39, and a guide plate 43b. The supporting member 38 and guide plate 43b are inserted between the head conbustion and the rear combustion chamber 11 via resilient sealing members 42a and 42b so that the whirling vane 37 will be free from displacement of the inner cylinder 4 due to the theremal expansion. The nozzle 34 secured to the nozzle flange 39 axially extends into the air hole defined by the vanes 37. Air for second stage combustion is introduced into the rear combustion chamber 12 through a guide portion formed by a guide member 43a supported by the suporting member 38 and a guide portion 43b of the guide plate, whereby the air is introduced smooth into the combustion chamber without producing eddy and without staying.

Combustoin of the second stage will be described below with reference to Figs. 17 to 19. The fuel 17 is introdced into a fuel reservoir 31 via a path 30 as shown in Fig. 19. The fuel nozzles 34 supply the fuel to the vicinity of air inlets or holes 33 trhat are open in the air path 32 of the second stage and in the rear combustion chamber 12. That is, the fuel of the second stage is supplied from the fuel reservoir 31 and is injected through fuel injection holes 35 along with the air stream through the air holes 33. The air stream 36 of the second stage is supplied into the main combustion chamber in the form of a whirling stream so that combustion time is extended as long as possible. The lean mixture is then supplied into the main combustion chamber where the gas is ignited by the flame of the head combustion chamber, and low-temperature lean combustion is established to decrease the formation of NOx. The key point to reduce the formation of NOx in the second stage is how to thoroughly mix air and fuel. The best method for this purpose is to extend the mixing time. In the

present invention, the whirling vanes 37 are provided to lengthen the air paths, and the fuel is supplied into the whirling streams flowing therethrough.

With regard to the combustion taking place in the second stage, furthermore, the important point is that the flame not be introduced into the air paths of the second stage and, particularly, that the flame not be introduced into the vanes 37. The air paths surrounded by the vanes 37 are establishing conditions that insure adequate combustion. However, the ejecting speed of a mixture of the air and fuel through the vanes 37 is about 100 meters/second, whereas the propagation speeed of flame in a turbulent flow is 5 meters/second at the fastest. Under ideal conditions, therefore, backfire does not occur. Depending upon the shape of vanes and finishing degree of the surfaces thereof, however, eddy of the mixture may develop near the wall surfaces of vanes, ahd the flame may be drawn into the vanes with eddy as the eddy is ignited, thereby causing backfire. To cope with this problem, the fuel 17 is injected form the injection holes 35 into the air paths surrounded by the whirling vanes 37. For this purpose, theinjection holes are between the whirling vanes. Furthermore, it is preferable that the upstream side of the whirling vanes 37 is curved as designated at 41a, 41b, 41c, as shown in Fig. 18, so as to be in alignment with the axis of the fuel nozzles 34, such that the fuel and the air are mixed together more desirably. No eddy or stagnation develops near the surfaces of the whirling vanes 37, and no backfire takes place. The injection holes 35 of fuel nozzles 34 positioned at the centers of air paths surrounded by the whirling vanes 37, facilitate homogeneously mixing the air and the fuel. Here, it is also important is that homogeneous mixing is not lost. The deviation in position between the whirling vanes 37 and the fuel nozzles 35 which is caused by the difference in the thermal expansion between the inner cylinder 4 and

the outer cylinder 5 that supports the fuel nozzles 35 of the second stage loses homogeneous mixing. The structure of Fig. 19 prevents the deviation.

The struction shown in Fig. 19 keeps to homogeneously mix the air and fuel for long time. Further, concentration of fuel is not diverted in the air path, and local hot spots are not formed. moreover, smooth flow of air by the curved portions 43a, 43b effects homogeneously mixing of the air and fuel. No eddy current or stagnation develops, and backfire does not develop, either.

Described below is the formation of NOx that is affected by theinterference of flame in the first satge and flame in the second stage and the air stream are introduced nearly at right angles (or it may be a shirling current) with the flame 45 of head portion from the rear portion 44 of the head combustion chamber, the flame 45 of head portion interferes as designated at 47 with the rear flame 46, thereby causing hot spots where the combustion temperature is high forming NOx in large amounts. As shown in Fig. 21 therefore, it is essential to divide the flame so that the flame 45 of head portion is not interfered with the flame 46 of rear portion, and that NOx is formed only in small amounts. Therefore, it can be contrived to direct the flame of the second stage toward a direction indicated by a dotted line 48. In this case, however, the fuel injected into the second stage is not ignited so quickly by the flame 45 of head portion. Therefore, the flame in the second stage cannot be outwardly directed excessively.

Fig. 21 shows in comparison the NOx concentrations, by ratio (NOx 2/NOx 1) of NOx in second stage to NOx in first stage, when the flame is directed in a horizontal direction as indicated by a curve A and when the flame is directed at right angles thereto as indicated by a curve B. Interference with the flame is reduced, and NOx is formed in reduced amounts when the flame is introduced in

a horizontal direction rather than in a direciton at right angles thereto.

As described above, a plurality of fuel nozzles are provided in the first stage and in the second stage, and the fuel is supplied from the outer circumferential portion of the combustor liners, in order to disperse the fuel and to homogeneously mix the air and fuel togethere. Therefore, combustion is effectively sustained under low-temperature and excess-air conditions, making it possible to greatly limit the formation of NOx. That is, as shown in Fig. 23, formation of NOx can be greatly limited in the first stage. Furthermore, with the second stage being combined as indicated by a line B, mush less NOx is formed compared with the conventional art indicated by a line A.

Fig. 24 illustrates how the combustion condition in the first stage affects the combustion condition in the second stge. Namely, Fig. 24 shows the distribution of gas temperature at the outlet portion of the head combustion chamber. According to the conventional art in which a single fuel nozzle is located on the axis, the temperature rises at the axis in the combusiton chamber. According to the present invention, however, the fuel is distributed well, and the air and the fuel are homogenerously mixed. Therefore, the high-temperature portion that was seen in the conventional art is not present here. As a matter of course, therefore, high-temperature portion that was seen in the conventional art is not present here. As a matter of course, therefore, high-temperature portions are likely to exist along the periphery. According to the present invention, furthermore, the cone is installed in the portion of axis, and cooling air is supplied. Therefore, no high-temperature portion develops along the axis. Namely, NOs is formed in greatly reduced amounts by first stage combustion.

According to the present invention, furthermore, the

temperature rises along the periphery greatly facilitating combustion in the second stage. That is, the combustion in the second stage is carried out with a lean mixture at temperature. The temperature rise along the periphery facilitates combustion, making it possible to reduce the formation of unburned components such as carbon monoxide (CO), unburned products (HC) and the like.

Fig. 15 shows the results of combustion tests using the combustor of the construction of the present invention. Compared with a conventional combustion system of a multiburner using an air-whirling flame stabilizer in an annular combustion chamber, the combuston system of the present invention helps reduce the formation of NOx by 30 % during the rated operation of a gas turbine. With regard to the flame stability, furthermore, it was confirmed that the combustion could be stably sustained over the operating range of the gas turbine.

What is Claimed is :

1. A gas turbine combustor (3) comprising ;

an axially elongated inner casing (4) having an upstream side end providing thereon an end wall (21) provided with a plurality of air hole annularly arranged therein and a downstream side end for exhausting a combustion gas (7) led to gas turbine (2) blades, said inner casing (4) defining a head combustion chamber (11) on the upstreams side and a rear combustion chamber (12) on the downstream side and having a plurarilty of air holes (19) formed in the peripheral wall defining said head cmbustion chamber (11);

an outer casing (5) so that an annular air passage is defined therebetween, and provided with an end cover (10) on the upstream side with a distance from said end wall (21) thereby providing an air passage communicating with said annular air passage ;

a hollow frustoconical tubular member (13) coaxially disposed in said head combustion chamber (11) of said inner casing (4) so as to project into said head combustion chamber (11) from said end wall (21), said tubular member (13) having a conical surface defining annular combustion space in cooperation with said inner casing (4), said annular combustion space increasing in cross-sectional area from the upstream side toward the downstream side, said tubular member (13) having a plurality of fine cooling air holes (24) on the surface in said head combustion chamber and a closed end on the downstream side ;

a fuel nozzle body, provided with a plurality of elongated fuel nozzles (22) annularly arranged, and secured to said end cover (10) so that said fuel nozzles (22) project into said annular combustion space through said air holes (24) of said end wall (21) so as to form gaps for air passage between said air holes (24) and said fuel nozzles (22), each of said fuel nozzles (22) having a fuel injection hole at its tip portion, said fuel injection holes being disposed in the vicinity of said air holes formed in said peripheral wall of said head combustion (11) on the upstream side;

a plurality of air inlets (23) annularly provided on said inner casing (4) for substantially axially introducing air into said rear combustion chamber (12); and

second stage combustion fuel nozzles provided for injection fuel into said air flows from said fuel inlets.

2. A gas turbine combustor (3) as defined in claim 1 wherein each of said fuel nozzles provided in said head combustion chamber 11 is opened nearly perpendicularly to the axis of said inner casing.

3. A gas turbine combustor (3) according to claim 1 wherein said air holes provided in the peripheral wall of said inner casing (4) are arranged in a plurality of row axially arranged with an interval therebetween, said rows having said air holes arranged annularly on the periphery of said inner (4) casing.

4. A gas turbine combustor (3) according to claim 3, wherein an axial position La of said air hole row on the most upstream side from said end wall (21) is within the range given as follows ;

$$La = (0.6 \sim 1.7) \times Lc$$

wherein Lc is a radial length corresponding to the difference in radius between said inner casing (4) and said tubular member (13) at said end wall (21),

and wherein the length Lb of said tubular member (13) from said end wall (21) to the downstream end is within the following range :

$$Lb = (2.0 \sim 5.20) \times Lf$$

wherein Lf is the position of said fuel injection holes most separated from said end (21).

5. A gas turbine combustor (3) according to claim 3, wherein the air supplied in said head combustion chamber (11) is in such ratios that the air is introduced in amounts of 8 % to 20 % through the air holes formed in said end

wall (21), air is introduced in amounts of 10% to 23% through said most upstream side hole row, and air is introduced in amounts 57% to 82% through the remaining of said air holes.

6. A gas turbine combustor (3) according to claim 1, wherein said fuel nozzles in said head combustor (11) have dissimilar lengths to change the position for injecting fuel into said combustion chamber.

7. A gas turbine combustor (3) according to claim 1, wherein said fuel nozzles projected in said head combustion chamber (11) are opened in the vicinity of said air hole row on the most upstream side so as to inject fuel thereabout.

8. A gas turbine combustor (3) comprising a head combustion chamber (11) in which fuel and air for a first stage combustion are introduced thereinto to burn, and a rear combustion chamber (12) in which fuel and air for a second stage combustion are introduced downstream of said head combustion chamber (11) and are burned,

the improvement comprising :

an inner tubular member (13) disposed coaxially of the axis of said head combustion chamber (11) to define an annular combustion space between said head combustion chamber (11) and said tubular member (13), said tubular member (13) having a front end on the downstream side and a plurality of fine holes for cooling air passage in the peripheral wall and said front end;

a plurality of fuel nozzles arranged in said annular combustion space for supplying fuel for the first stage and opened more downstream than the upstream side end of said head combustion chamber (11) so as to subject the injected fuel to voltexes including both upward flows and downward flow thereby stabilizing flame resulting from said first stage combustion ; and

a plurality of second stage nozzles provided close to the periphery of said rear combustion chamber (12) and more downstream than said front end of said inner tubular member (13) for substantially axially injecting fuel for said second stage into the interior of said rear combustion chamber (12).

9. A gas turbine combustor (3) according to claim 8, wherein each of said second stage fuel nozzles has a plurality of fuel injection holes at the tip portion, and said fuel injection holes are inserted between whirling vanes (37) forming air pathes of said second stage.

10. A gas turbine combustor (3) according to claim 9 wherein said whirling vanes (37) have openings in the direction in which the air is ejected nearly in parallel with the axial line of the combustor.

11. A gas turbine combustor (3) according to claim 8, wherein the length of said head combustion chamber (11) along the axial line thereof is greater, by 1.2 times but not more than 1.8 times, than the outer diameter of said head combustion chamber (11).

12. A gas turbine combustor (3) according to claim 9, wherein said whirling vanes (37) having portions in parallel to said second stage fuel nozzle (34) axis and portions inclined so as to form whirling air stream flowing substantially in parallel to the axis of said combustion chamber.

13. A gas turbine combustor (3) according to claim 9, wherein said whirling vanes (37) are supported by a member defining said head and rear combustion chambers through resilient sealing members so that said whirling vanes (37) are free of the displacement of said member due to thermal expansion, and guide members are provided for guiding air to flow smoothly into between said whirling vanes (37).

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FIG. 1

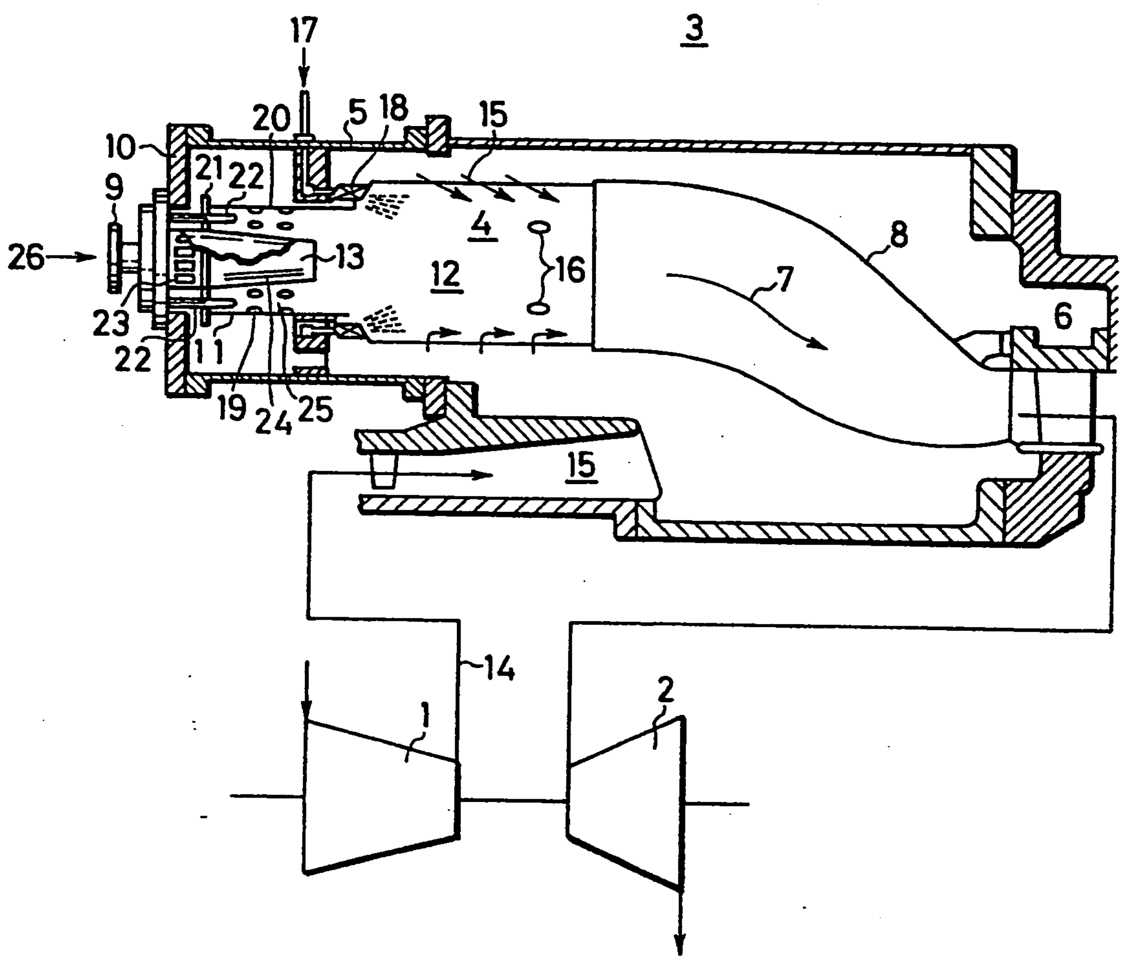

FIG. 2

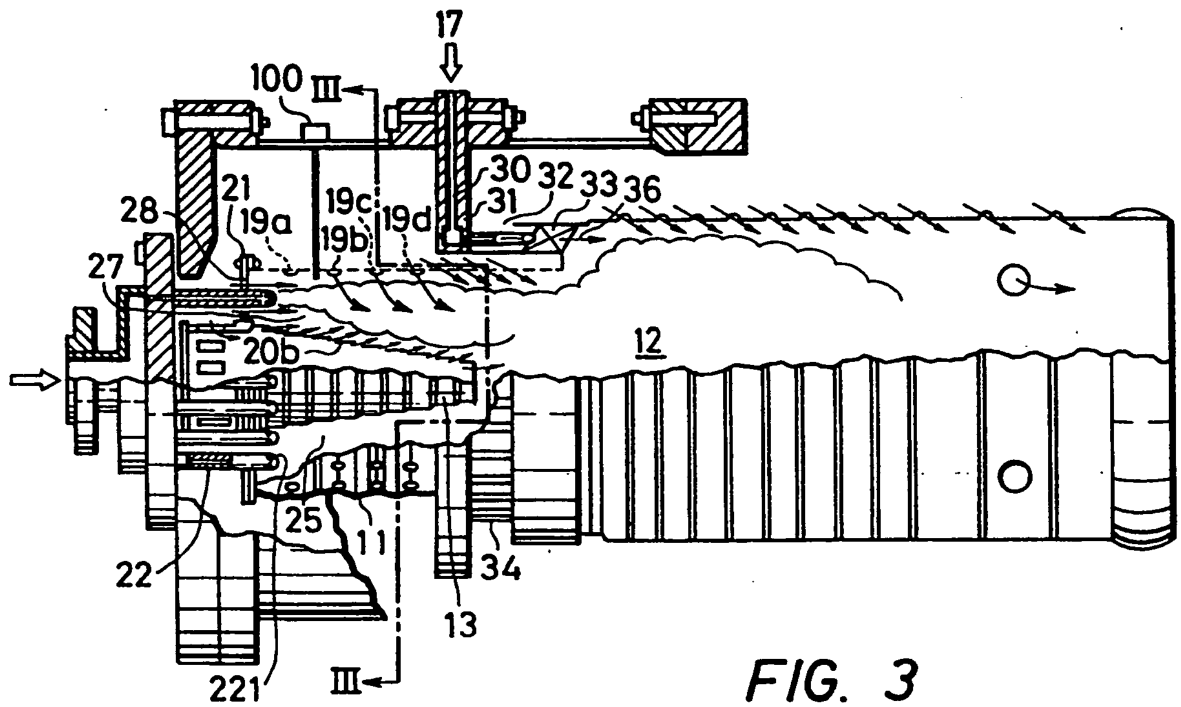

FIG. 3

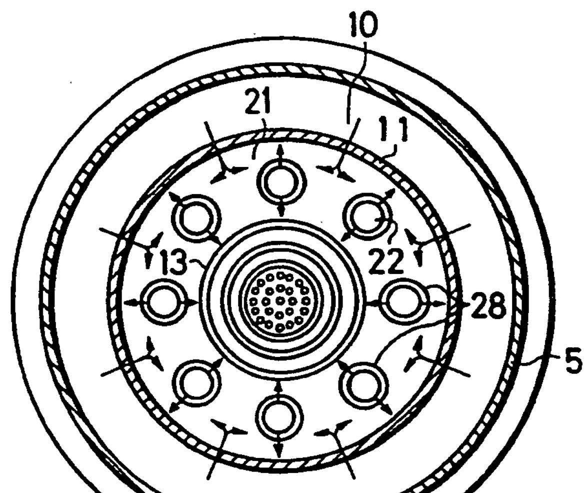

FIG. 4

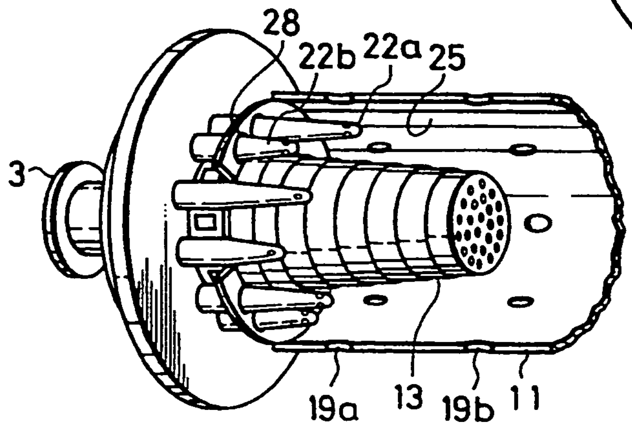

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FIG. 5

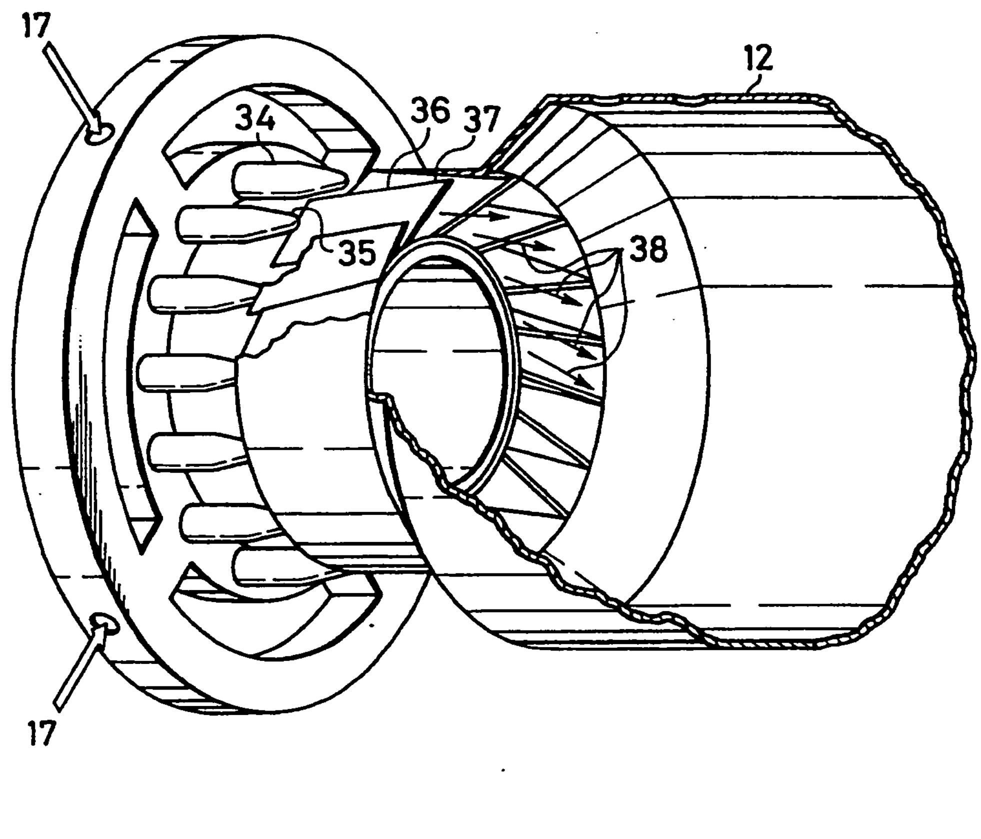

FIG. 6

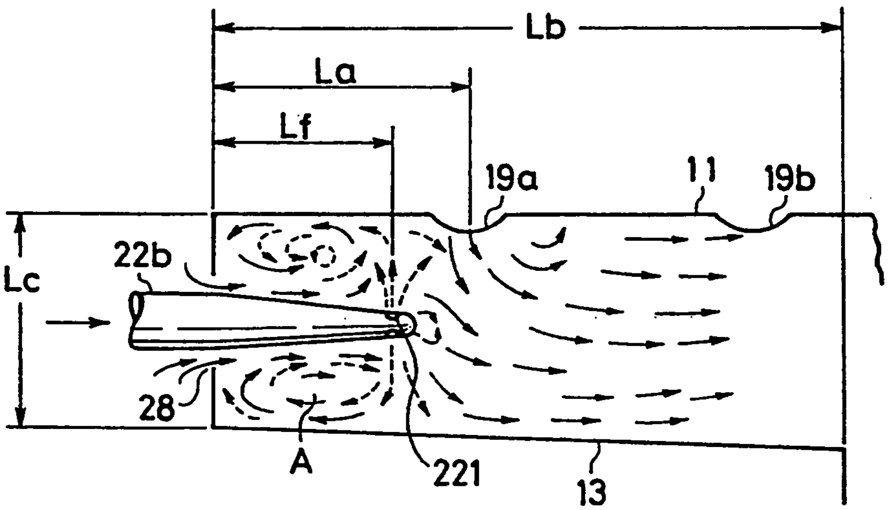

FIG. 7

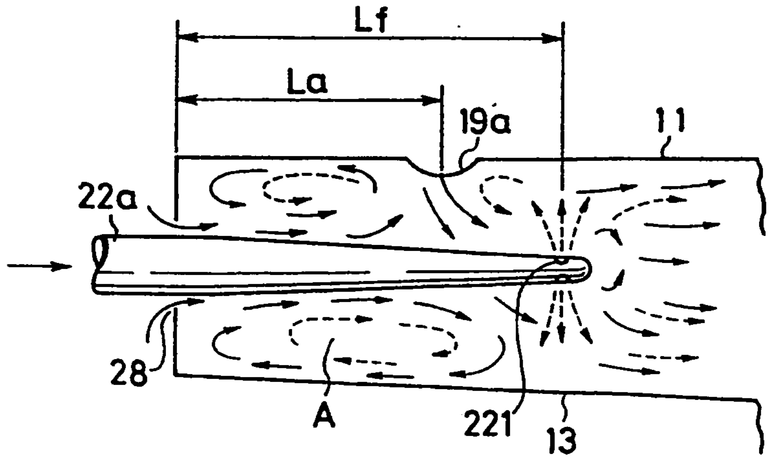

FIG. 8

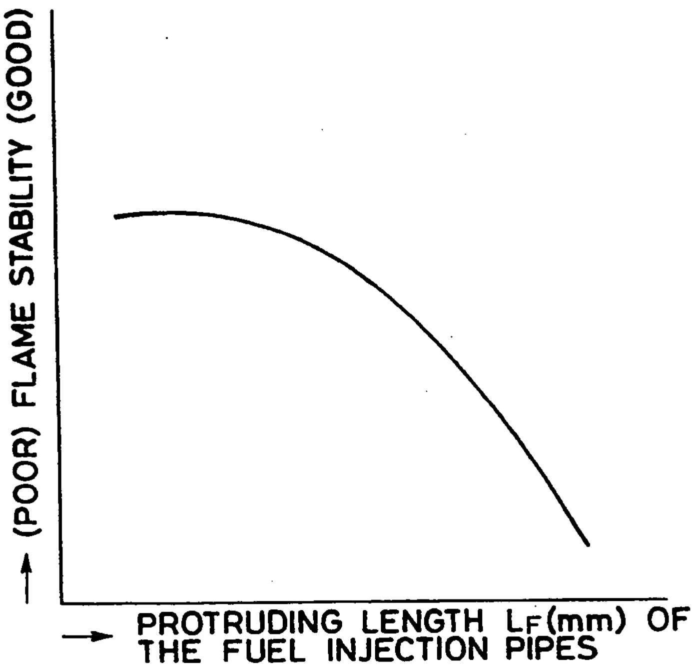
↑ (POOR) FLAME STABILITY (GOOD)
→ PROTRUDING LENGTH LF(mm) OF THE FUEL INJECTION PIPES

FIG. 9

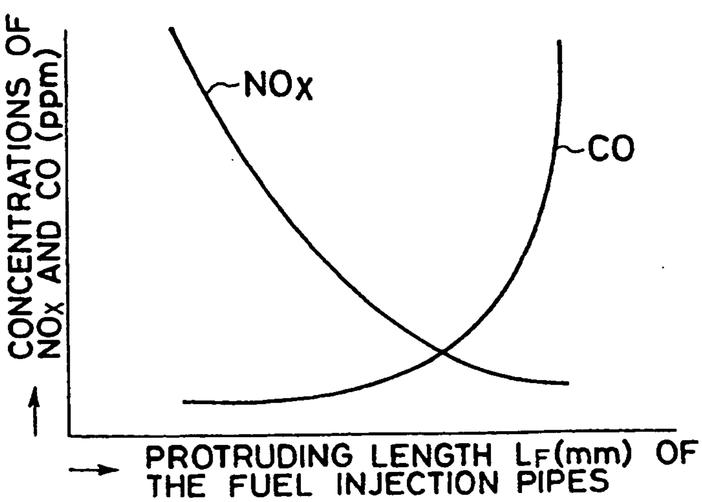
↑ CONCENTRATIONS OF NOx AND CO (ppm)
NOx
CO
→ PROTRUDING LENGTH LF(mm) OF THE FUEL INJECTION PIPES

FIG. 10

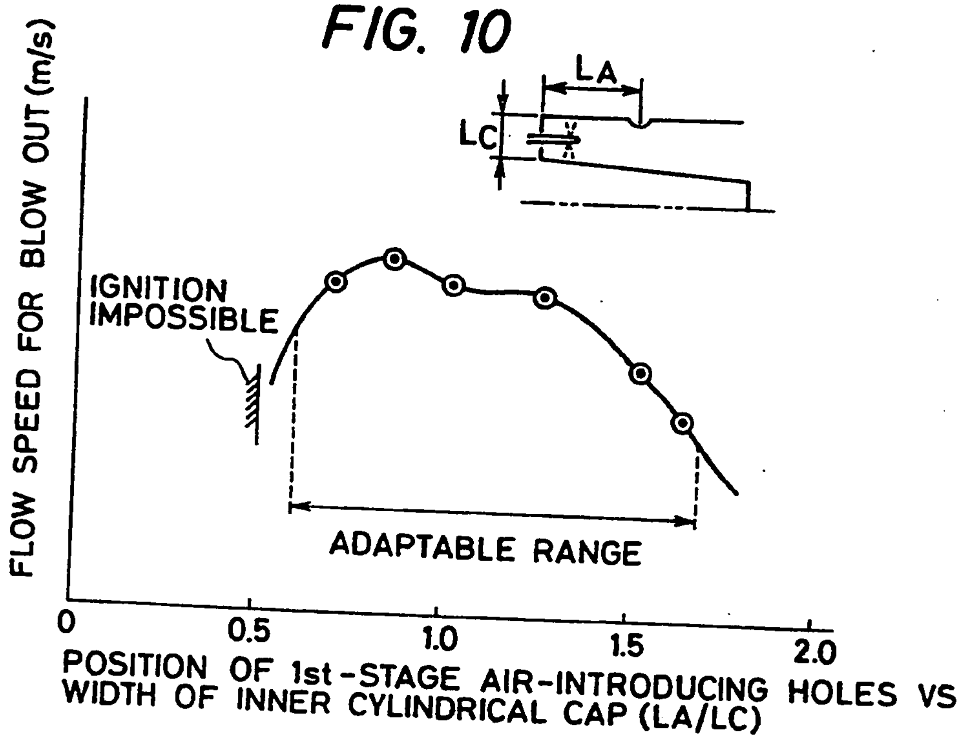
LA
LC
FLOW SPEED FOR BLOW OUT (m/s)
IGNITION
IMPOSSIBLE
ADAPTABLE RANGE
0
0.5
1.0
1.5
2.0
POSITION OF 1st-STAGE AIR-INTRODUCING HOLES VS.
WIDTH OF INNER CYLINDRICAL CAP (LA/LC)

FIG. 11

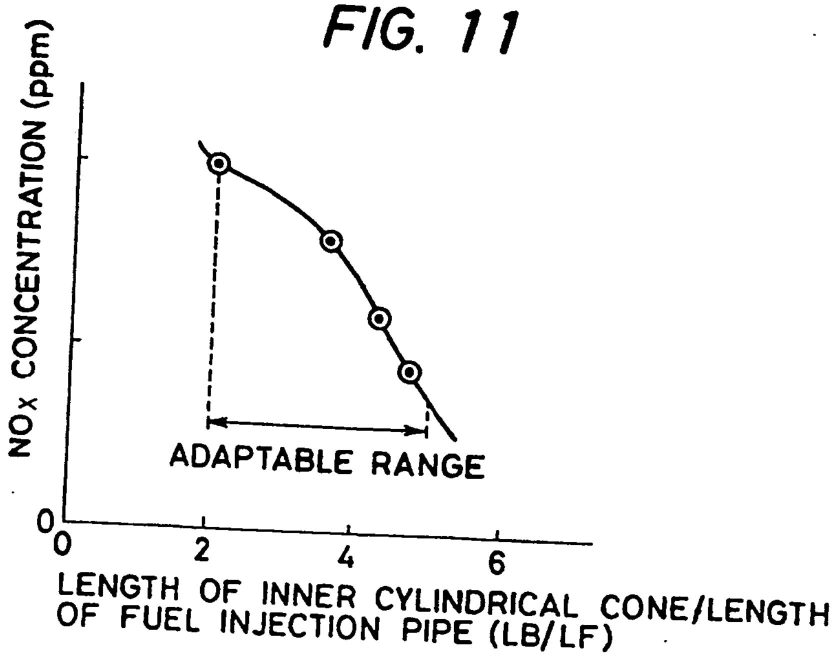
NOx CONCENTRATION (ppm)
ADAPTABLE RANGE
0
0
2
4
6
LENGTH OF INNER CYLINDRICAL CONE/LENGTH
OF FUEL INJECTION PIPE (LB/LF)

FIG. 12

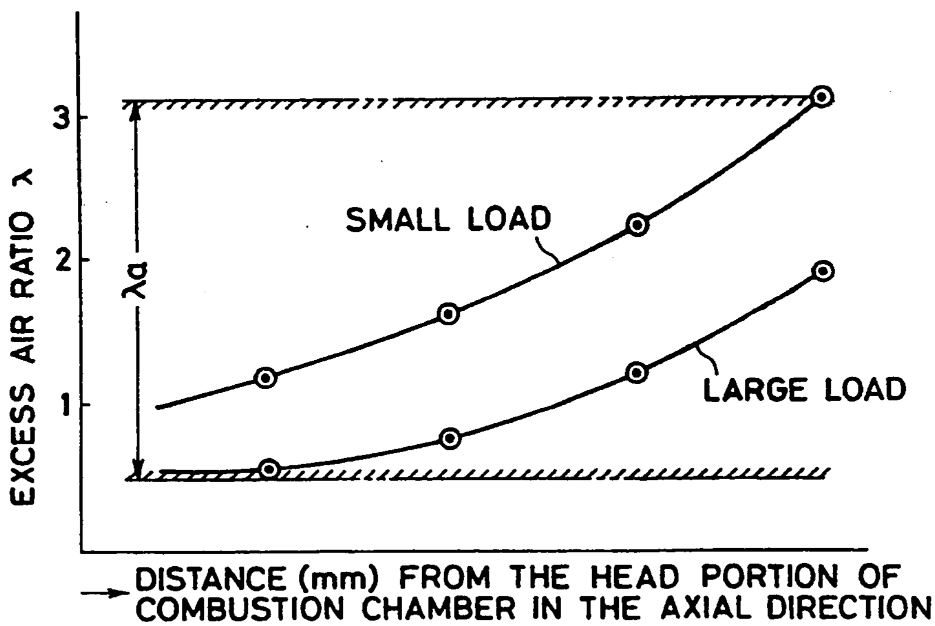
EXCESS AIR RATIO λ
3
2
1
λa
SMALL LOAD
LARGE LOAD
DISTANCE (mm) FROM THE HEAD PORTION OF COMBUSTION CHAMBER IN THE AXIAL DIRECTION

FIG. 13

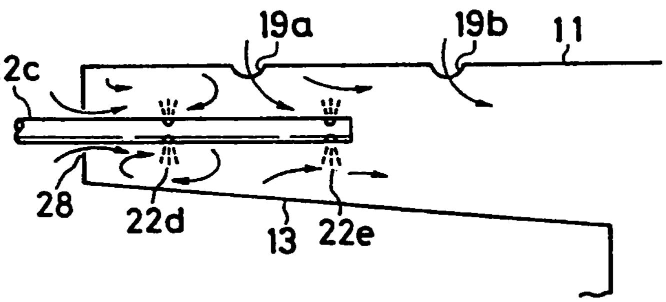

FIG. 14a

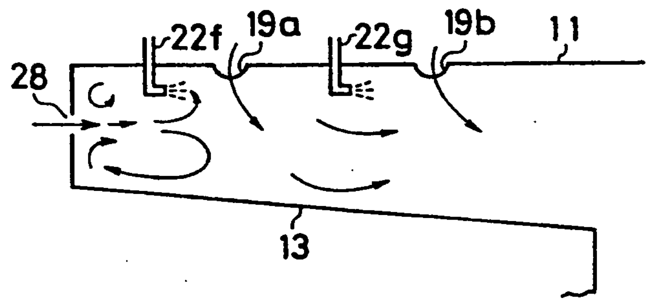

FIG. 14b

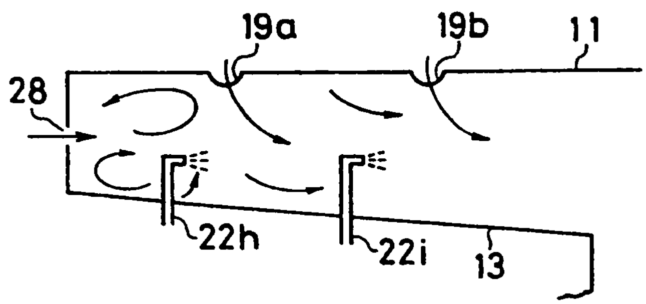

FIG. 15

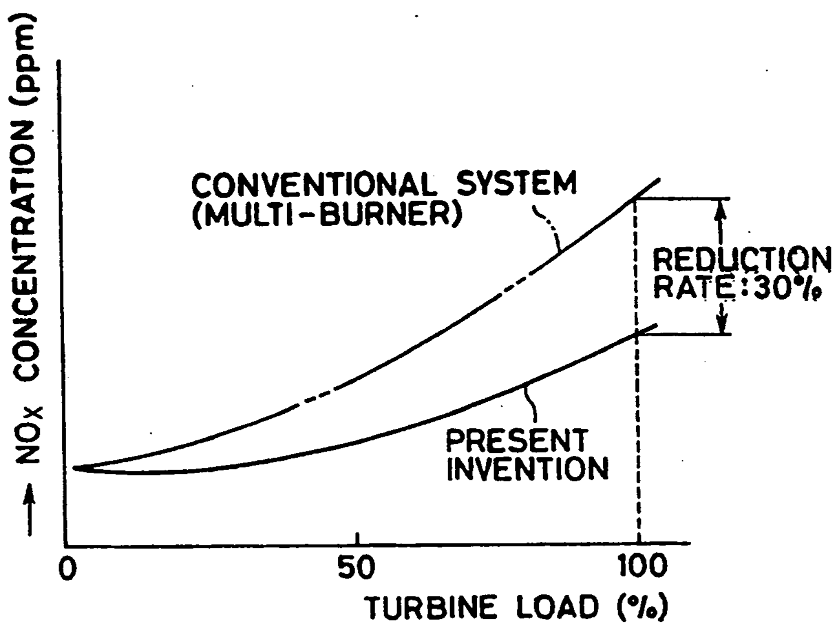
NOx CONCENTRATION (ppm)
CONVENTIONAL SYSTEM
(MULTI-BURNER)
REDUCTION
RATE:30%
PRESENT
INVENTION
0
50
100
TURBINE LOAD (%)

FIG. 16

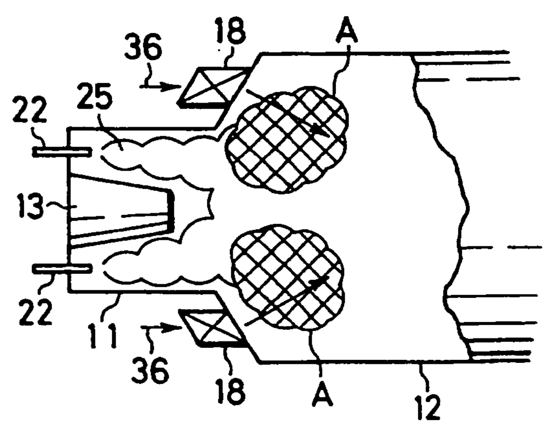
36
18
A
22
25
13
22
11
36
18
A
12

FIG. 17

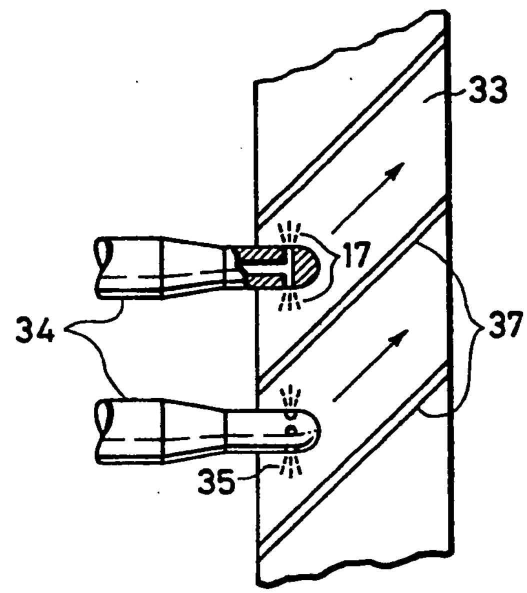

FIG. 18

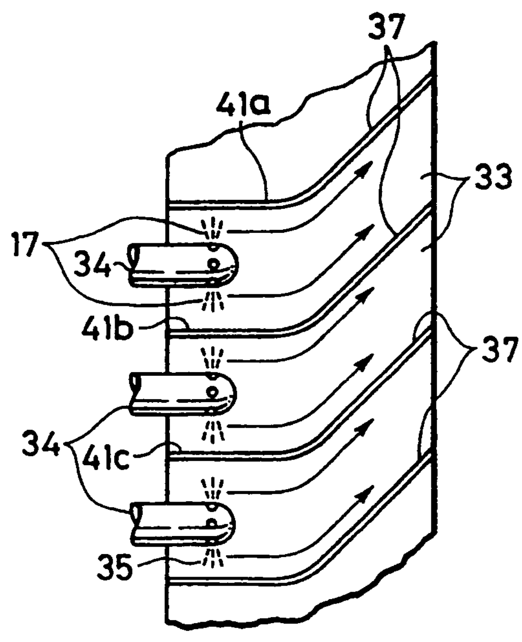

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FIG. 19

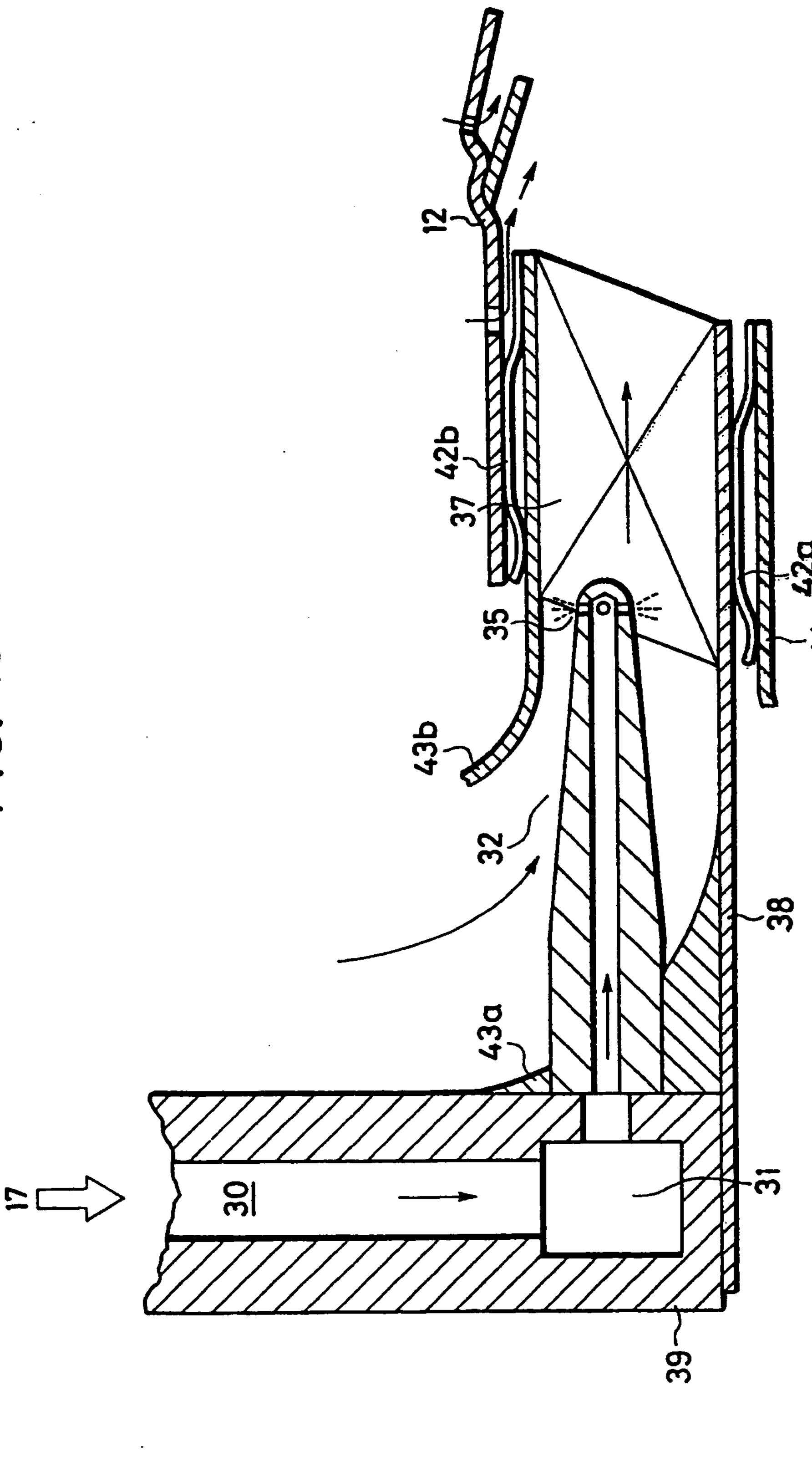


FIG. 20

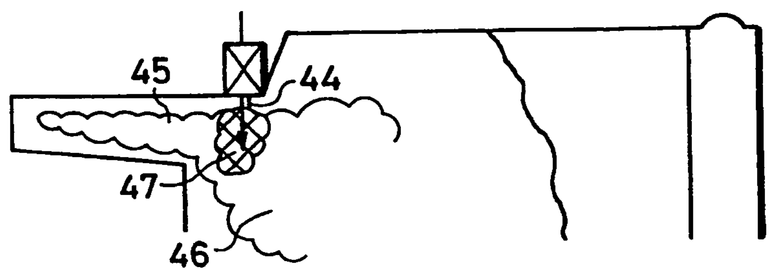


FIG. 21

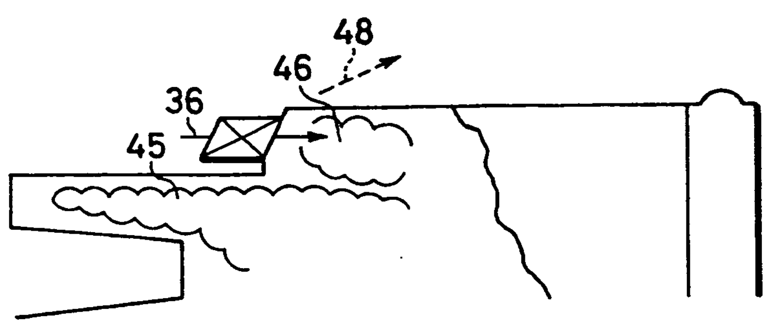


FIG. 22

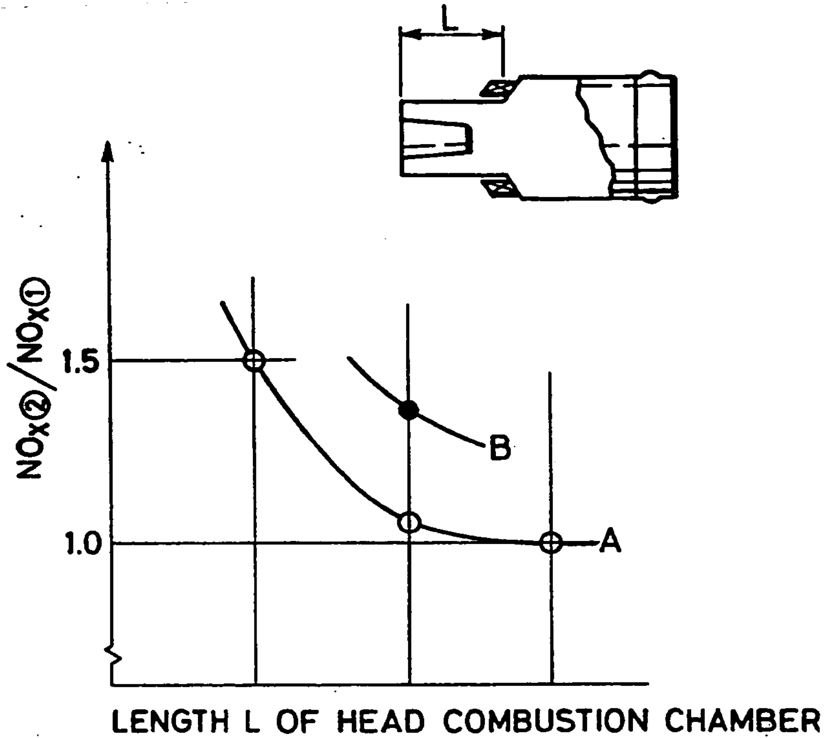

L
NO_x② / NO_x①
1.5
1.0
A
B
LENGTH L OF HEAD COMBUSTION CHAMBER

FIG. 23

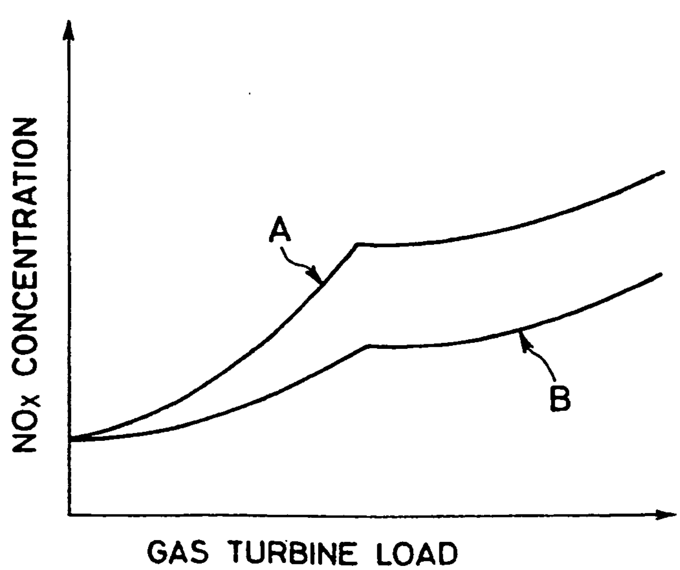
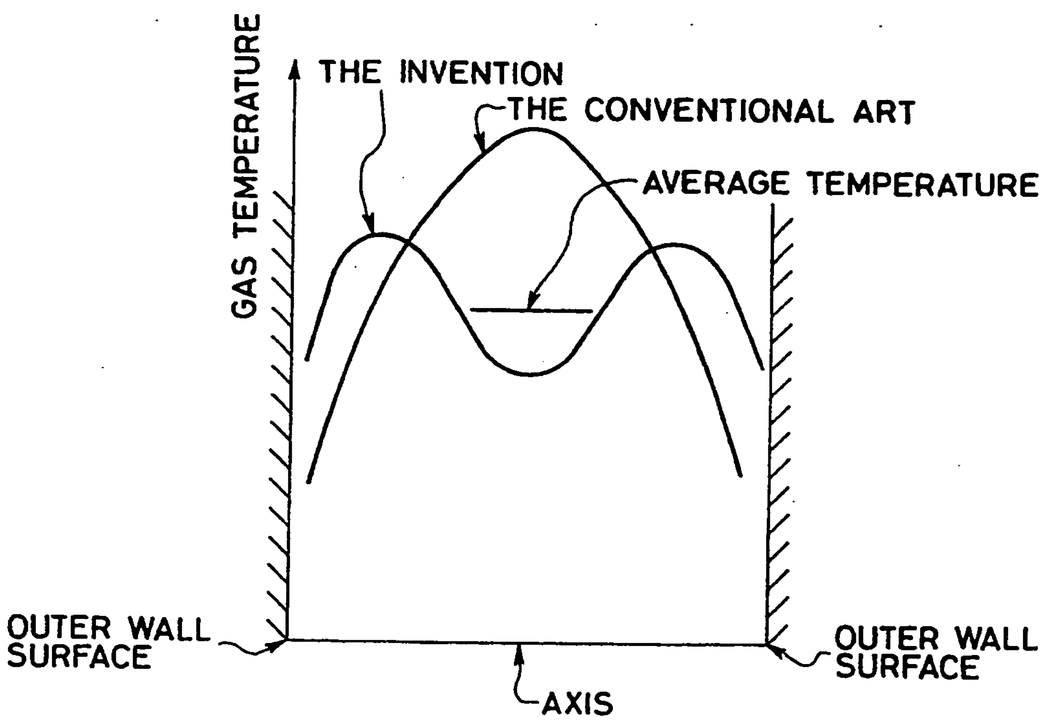

NOx CONCENTRATION
A
B
GAS TURBINE LOAD

FIG. 24


GAS TEMPERATURE
THE INVENTION
THE CONVENTIONAL ART
AVERAGE TEMPERATURE
OUTER WALL SURFACE
OUTER WALL SURFACE
AXIS

European Patent Office

EUROPEAN SEARCH REPORT

0169431

Application number

EP 85108445.9

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl 4)
A	US - A - 4 292 801 (WILKES et al.) * Totality; especially fig. 1-3, 8 * --	1,3,8	F 23 R 3/34 F 23 R 3/04
A	DE - A1 - 3 217 674 (HITACHI, LTD.) * Totality; especially fig. 1-3, 6-9 * --	1,3,8-10	
A	US - A - 4 344 280 (MINAKAWA et al.) * Fig. 3,4 * --	1,8	
A	GB - A - 2 097 113 (GENERAL ELECTRIC COMPANY) * Totality * --	1,8	TECHNICAL FIELDS SEARCHED (Int. Cl 4)
A	US - A - 2 676 460 (BROWN) * Totality * --	1,8	F 23 R 3/00 F 02 C 7/00
A	US - A - 4 151 713 (FAITANI et al.) * Totality * ----	1,3,8	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	11-10-1985	PIPPAN

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document
T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document